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Feasibility Study of Vessel Entry and Exit Behavior Using the Gulf of Mexico Shrimp Fishery Data Set from 1965-80

by:

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Introduction[1]

In common property resources such as the Gulf of Mexico shrimp fishery, changes in economic and biological conditions affect the level of fishing effort applied by fishermen. In an open access fishery, the equilibrium level of effort is maintained where total revenue equals total cost in economic terms. Therefore, any increase in price or decrease in costs will result in an expansion of effort until the normal economic profits are dissipated for the last vessel in the fishery. The expansion in effort can be short term (less than a year) or long term. Effort levels can be expanded in the short run via changes in the variable factors of production such as crew size, days fished, and the amount or type of gear used by the vessel. In the long run, the fixed factors of production such as vessel length, hull material, and engine horsepower can be adjusted by the entry of new vessels into and exit of old vessels out of the fishing fleet. Changes in the number of vessel in the fishing fleet caused by entry and exit behavior can be studied by examining these long run adjustments in fishing effort.

Attempts at modelling the changes in the size and structure of the fleet from vessel entry and exit behavior have resulted in the assembly of a data set collected by the National Marine Fisheries Service (NMFS). Specifically, the NMFS vessel operating units file (VOUF), the shrimp landings file (SLF) for the Gulf of Mexico shrimp fishery, and a cost and returns survey (CNR) conducted by National Marine Fisheries Service in 1983 for the 1982 shrimp fishing year have been merged for this purpose. This paper describes the underlying data sets, presents trends in fleet size and net entry of vessels as reported in both the SLF and the VOUF and presents preliminary research results of correlations with various explanatory variables such as price per pound, a set of equations explaining the correlations between economic and biological variables and fleet size, and derived demand equations for factor inputs used in the shrimp fishery. Although the research needs further refinement, the results indicate that combining the existing data sets provides sufficient information to track trends in the size and structure of the fleet and to model vessel entry and exit behavior.

Description of the Available Data

Primary data from NMFS is used for this analysis. The VOUF contains information about individual vessel characteristics indexed by the United States Coast Guard (USCG) vessel documentation or identification number. This data set contains information about the universe of vessels that operate in the fisheries of the southeastern region of the United States. The SLF contains information on the pounds, value, and to a limited extent fishing effort for those vessels that land shrimp in the Gulf of Mexico by USCG vessel documentation number. The CNR data set contains input cost and

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1 C:\WP5\URI\VEEFSA.RPT

behavior information by USCG vessel documentation number for a sample of shrimp vessels operating in the southeastern region in 1982. Other sources of data for this analysis include published information from *Fisheries Abstract of the United States, Fishery Statistics of the United States,* the *Statistical Abstract of the United States,* and the *Survey of Current Business.*

The VOUF contains information on vessel characteristics from 1965 through 1981.[2] A vessel is defined according to the USCG to be any craft in excess of five gross tons. The vessel characteristics that are included in this data set are the vessel's name and USCG documentation number, the amount of full and part time crew, the hull material, the gross tonnage, the length of the hull, the year the vessel was constructed, the engine type and its horsepower, the type (otter trawl), number (two trawls), and quantity (2900 yards of net) of all types of gear the vessel was reported to have used, the state, county, and region where the vessel operated, and the number of auxiliary boats with and without motors used by the vessel.

The SLF contains information on the landings and value of vessels operating in the Gulf of Mexico from 1964 to 1988. Information in this data set includes the vessel documentation number, the port where the vessel landed its catch, the date of the landing and the trip, the number of trips the catch represents, whether the shrimp were machine or box graded for size, whether the information was collected as part of the dealer census or as a fisherman interview, the species and size of the shrimp, the pounds and value of the catch, whether it is reported in heads-off or heads-on weight (landings type), and fishing effort data such as the water, area, and depth where the shrimp were caught and the number of hours of actual fishing time in 24 hour units (days fished).

These data sets contain multiple records for an individual vessel documentation number. An entry is made in the VOUF data file for each port in which that vessel was observed landing a catch, for each type of gear the vessel used, for each time its crew size changed, etc. for a particular year. The SLF's multiple records correspond to the size distribution, species of shrimp, and landings type of the shrimp caught, the size grading method, and the port of landing primarily on a per trip basis. Some entries in this file contain information on multiple trips for a particular vessel documentation number. The SLF also contains a large number of consolidated records that exclude individual vessel documentation numbers. The consolidated record number discriminates between vessel and boats and between states. The exclusion of unique vessel documentation numbers, however, prevents comparisons between the SLF and the VOUF data sets for a particular vessel. Since the consolidated records capture some of the trips made by a vessel, for example, comparisons of total catch by vessels of different lengths are made difficult. Also, using the SLF to make comparisons of

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2 The VOUF covering the 1982 to 1986 time period are presently being updated and will be included in this analysis when they are complete.

different years to determine vessel entry and exit patterns may exclude vessels from their proper behavior categories because they are represented in the consolidated records.

The data contained in the VOUF and the SLF were collected by a NMFS fishery reporting specialist (port agent). For the VOUF, the port agents would note each time a new vessel entered a port for which they had responsibility and record its characteristics such as crew size, gear type, and length. For the SLF, the port agents would collect census data from the fish dealers in each port and interview a sample of fishermen for effort related information. As a result, the portion of the SLF pertaining to dealer census records does not contain fishing effort information such as days fished or the water, area, and depth codes. The fisherman interview portion of the SLF does contain fishing effort information, but represents approximately ten percent of the records in each data file.

Changes in the data collection method have occurred over the time period of the analysis. From 1964 to 1975 and from 1981 to present, the data collection method for the SLF was based on a dealer census. In addition, a random sample of fishermen was conducted to collect fishing effort information. Beginning in 1976 and continuing to 1980, a sampling approach was adopted. Individual vessels were sampled for fishing effort and catch data and dealers were interviewed for price data. These data were then combined and expanded to represent the total catch of shrimp in the Gulf of Mexico shrimp fishery.[3] Unfortunately, the individual vessel documentation numbers were lost in the expansion algorithm. The original data were available from NMFS in Washington, D.C. Using these data in the analysis required combining the vessel interview files with the dealer files to generate the missing ex-vessel price and value information by vessel documentation number.

Although information on fishing effort in the form of vessel characteristics, harvest levels, and market exvessel prices are available from the VOUF and SLF data sets, input cost information is not routinely collected by the NMFS or state/local government agencies. In 1983, the NMFS did collect cost and returns (CNR) information from fishermen operating in the Gulf of Mexico and the southern Atlantic states shrimp fisheries for the 1982 fishing year. This stratified random sample based on port, ownership, mobility, state, vessel size, bycatch utilization and non-shrimp participation level was collected through personal interviews with fishermen, vessel owners, and accountants by a private contractor.[4] The resulting data set contains detailed information on the fishing firm's name and USCG documentation number, input costs (groceries, fuel, share for crew, vessel, and captain, ice), factors of production (numbers of trips and days fished inshore and offshore, vessel tonnage and length, type of hull,

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3 Region 4; gear code 215.

4 DRA/Centaur Ass. Contract No. NA82-GA-C-000421.

gallons of fuel, pounds of ice, engine horsepower, crew size, and type of gear), fixed costs (insurance, depreciation, and maintenance and repair), the output mix of species harvested as bycatch and from other fishing operations, and exvessel prices. Of the 193 interviews conducted, 21 came from Texas, 60 from Louisiana, 20 from Alabama, 9 from the east coast of Florida, 24 from Georgia, and 59 from South Carolina.

The resulting data set assembled from the CNR, VOUF, and SLF provided information on nearly all aspects of the shrimp fishing industry. Contained within it are data on pounds landed, value of the catch, fishing effort, input costs, USCG vessel documentation numbers, and vessel characteristics for this fishery resource. Although this data set was not collected explicitly for economic research and the cost data associated with operating in this fishery had to be approximated, sufficient information is available to study the causes of vessel entry and exit behavior.

Suitability of the VOUF and SLF Data for Analysis of Entry/Exit Behavior in the Gulf of Mexico Shrimp Fishery

The suitability of the data sets for the analysis of vessel entry and exit behavior is determined by first comparing the trends in and the correlations between different entry and exit categories created using the VOUF and SLF. Then, the data sets are combined to determine if entry and exit behavior is correlated with economic variables. Lastly, a simple set of econometric equations were developed to determine if the causal variables that underlie vessel entry and exit behavior could be identified.

SLF - VOUF Comparison

The suitability of the data sets for the vessel behavior analysis was determined by comparing the trends in and the correlations between different entry and exit classifications as determined by the VOUF (according to the gear and region codes) and by the SLF. A count of the vessels in the respective data files by vessel documentation number for each year provided a list of vessels that accessed the Gulf of Mexico shrimp fishery. This list was then compared to a prior year and a subsequent year to determine the entries to and exits from the base year fishery. A vessel entered the base year fishery if it was not in the previous year's data file, but was in the base year file. A vessel exited the fishery if it appeared in the base year file, but not in the subsequent year file. One additional category was established for vessels that entered and exited the shrimp fishery; it was in the base year file, but not in either the previous or subsequent year files. The trends found in the VOUF were then compared to those contained in the SLF for the Gulf of Mexico.

The pattern of entry and exit behavior found in the two data sets differed significantly on a yearly basis. Table 1 presents the number of vessels that entered, exited, and remained in the Gulf of Mexico shrimp fishery according to the VOUF and SLF for 1966 to 1979. Between 29.8 and 98.7 percent of those vessels reported to be operating in this fishery by the VOUF can be found in the SLF; between 3.9 and 83.5 percent of those vessels reported to have entered; and between 10.5 and 90.0 percent of those reported to have exited. On average, 72.8 percent of the vessels in the fishery, 50.1 percent of the entering vessels, and 48.1 percent of the exiting vessels as determined by the VOUF can be matched with vessel documentation numbers found in the SLF between 1966 and 1979.

A comparison of the VOUF and SLF vessel behavior trends indicates a poor relationship over time for the categories of vessels in the fishery (Figure 1) and vessels entering the fishery (Figure 2). While the number of vessels in the shrimp fishery has increased according to the VOUF, the SLF indicated a downward trend in Figure 1. The correlation coefficient ($r = -0.612$) indicates that as vessels in the fishery increase according to the VOUF, vessels in the fishery according to the SLF decline. The correlation coefficient ($r = -0.182$) for vessels entering the fishery (Figure 2) indicates a similar though much weaker relationship between the time trends in the two sets of data files. In Figure 3, the relationship between the time trend for the vessel exiting the fishery was stronger and in the right direction ($r = 0.670$). That is, changes in the number of vessels exiting the fishery in both data sets tend to move in the same direction at the same time.

Figures 1 through 3 suggest a closer correlation between the time trends observed in the two data sets, if the 1976 to 1980 data are excluded. For vessels in the fishery, the correlation coefficient increased from -0.612 to 0.285; from -0.182 to 0.827 for vessels entering the fishery; and from 0.670 to 0.911 for vessels exiting the fishery. This suggests that the SLF data collection method used from 1976 to 1980 may be responsible for the poor overall correlation between the time trends in the two data sets when used for this type of economic analysis.

For the entire data set, these figures and the reported correlation coefficients indicate that the SLF alone does not accurately represent the vessel entry and exit patterns in this fishery. The consolidated records contained in this set of data files conceal information about individual vessel operations. Since only an average of 72.8 percent of the vessels reported operating in the shrimp fishery by the VOUF are reported catching shrimp in the SLF, 27.2 percent of the vessels in the shrimp fishery are not consistently identified by either data set. Eliminating the 1976 through 1980 SLF data would result in an improvement in the quality of this data set, but information about changes in vessel behavior during this five year period would be lost. If VOUF and SLF data do not accurately reflect actual entry and exit behavior, the economic models built using this data will not provide insight into the causes of the observe vessel behavior.

Combined Data Set

Combining the VOUF and SLF on a per vessel basis resulted in a viable data set from which entry and exit behavior could be modeled. The consolidated records in the SLF and the change in the method of data collection prevent an accurate determination of the entry and exit behavior patterns. However, the economic data in the SLF on a per vessel basis appears to be well behaved. The trends in vessel entry and exit behavior can be determined from the VOUF as well as the short and long run trends in vessel characteristics and the economic information for a subset of each group can be drawn from the SLF. Combining this information generates a data set capable of explaining the short and long run fluctuations in the structure and size of the fleet from vessel entry and exit behavior caused by changing economic and biological conditions.

Figures 4 through 6 present the revenue and pounds landed per trip and trips per vessel information from the SLF organized by vessel behavior category as determined by the VOUF. Vessels that entered the fishery generated a higher revenue per trip (averaging $3600) and pounds per trip (averaging 2322 lbs.) than vessels that are in the fishery ($2556 and 1680 lbs.); Figures 4 and 5, respectively. This could reflect both the barriers to entry that must be overcome by entering vessels and the increased fishing power of newer vessels. Vessels that exited the fishery had lower revenue (averaging $1990) and pounds per trip (averaging 1285 lbs.) than vessels that remained in the fishery. This should reflect their relatively poorer financial performance that would cause them to search for better opportunities elsewhere. The last group of vessels, those that entered and exited the fishery, generally report slightly higher pounds (averaging 1413 lbs.) and lower revenue (averaging $1,267) per trip than those vessels that exited the fishery. Since the correlation coefficient for the vessel entry and exit behavior category was positive for above average fishing years ($r = 0.209$) and negative for below average years ($r = -0.112$), this category may represent opportunistic behavior by vessels that operate primarily in other fisheries but perceive potential profits for short periods in the shrimp fishery.

The trips per vessel by behavior category in Figure 6 also exhibited an interesting pattern. Vessels in the fishery had the highest number of trips per vessel (averaging 17.9). This was followed by vessels in the entering category with 9.9 trips per vessel, vessels in the exiting category with 8.7, and lastly by vessels in the entering and exiting category with 5.3 trips per vessel. One explanation[5] for this observed behavior is that vessels in the fishery would be making trips from the beginning to the end of the fishing season. Entering or exiting vessels would not be in the fishery as long and vessels that both entered and exited in the same year would be in the fishery the least amount of time.

Once the vessel behavior categories are accounted for, the average number of annual trips per vessel for the vessels in the fishery of 17.9 is not that different from the estimate of 20 to 25 trips per vessel provided by the port agents.[6] If the years 1976 to 1979 are

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5 Alternative explanations, including multispecies fishing operations, seasonality in the shrimp fishery, region where fishing activities occurred, etc., could also account for this observed behavior (Per. comm. Richard Raulerson).

6 E. Snell, personal communication.

excluded, the annual average in this vessel behavior category would rise to 21.8 trips per vessel. The 1976 to 1979 time period indicates a significant decline in the trips per vessel by behavior category. The change in the data collection method is more likely responsible for this decline than is a change in economic conditions. Also, the consolidated records contained in the SLF apparently conceal some of the trip information for each vessel identified by an unique USCG documentation number.

Figures 7 through 11 present trends in vessel characteristics for the shrimp fishing fleet derived from the VOUF. Except for crew size, a general upward trend exists for each of these vessel characteristics. The average gross tonnage of a vessel (Figure 7) has risen from approximately 45 tons in 1965 to 69 tons in 1980. A general increase in fishing effort has, therefore, been occurring over this time period presumably caused by improving economic or biological conditions in the fishery. The standard errors presented in Figure 7 through 11 have been increasing and fluctuating around their mean values for each vessel characteristic. Vessel length in Figure 8 increased from a mean value of about 52 feet with an one standard error range of 43 to 62 feet in 1965 to a mean value of 56 feet in 1980 with an one standard error range of 43 to 69 feet. This implies that the fishing fleet has become more heterogenous over time. These two trends imply that newer and more powerful vessels have entered the fishery and the characteristics of these vessels have become increasingly diverse. As a result, vessel's may be specializing in the characteristics that allow them to catch a specific size range of shrimp more efficiently; e.g. a large vessel, offshore fleet and a small vessel, inshore fleet.

The fluctuations exhibited in Figures 7 through 11 probably reflects the fleet response to short run changes in the economic and biological conditions in the fishery. In Figure 9, the steady increase in mean horsepower was accompanied in 1969 to 1973 by an increase and then a decline in the range of horsepower found in the fleet. In Figure 10, peaks in crew size occurred in 1967 and in 1977. A peak also occurred in 1976 for the year the vessel was constructed (Figure 11). Vessels in other fisheries may have entered the shrimp fishery to take advantage of what was perceived to be a particularly good fishing year and then exited the fishery in the following year. The fluctuation in horsepower may have been caused by the increase in price and reduced availability of fuel during this period of time. Changes in fishing strategy may have increased the variability of vessel characteristics in below average fishing years with unsuccessful vessels exiting the fishery and reducing the variability in future years. Whatever their causes, these short run fluctuations affect the structure of the fishing fleet through vessel entry and exit activity.

The correlation coefficients for the various explanatory variables that should describe the vessel entry and exit behavior are presented in Table 2. Both vessel entry and fleet size decline in below average fishing years and increase in above average years. Vessel exits, however, increase in below average fishing years and decline in above average years, but the relationship is much weaker. These coefficients imply that vessels are less likely to leave the fishery as economic conditions decline then they are to enter the fishery when economic conditions improve.

Increases in the real price per pound of shrimp are strongly correlated with fleet size and vessel entry and have a weak positive correlation with vessel exit levels. The cost variable represented by the mean prime rate based on the year of vessel construction was also positively related to vessel entry, exit, and fleet size. However, behavior patterns should be determined by changes in prices relative to costs. Both costs and prices can increase overtime and be positively correlated with fleet size increases, but if prices increased faster than costs, the ratio of prices to costs should be positively related to vessel entry levels and fleet size and negatively related to vessel exit levels as Table 2 indicates.

Vessel exit levels are weakly correlated with the price, cost, and revenue measures in Table 2. These weak correlations tend to support the contention that vessels tend not to exit the fishery because economic conditions are declining. Instead they attempt to increase their share of landings by increasing the number of trips and pounds landed. Trips per vessel for vessels in the fishery, entering, exiting, and entering and exiting in the same year are positively correlated with below average fishing years and negatively correlated with above average fishing years. As the economic conditions improve trips per vessel remain constant or decline. The correlation coefficients for pounds in Table 2 indicate that as price and the price cost ratio decline, pounds landed increase in what may be an attempt by the vessels to offset the fall in the resource's value. As economic conditions decline, these strong negative correlation coefficients imply that more effort is put into maintaining the vessel's economic viability, i.e. fleet size is sticky downward.

Vessel entry and fleet size behavior were also found to be negatively correlated with the number of trips, the length of the vessel, the year the vessel was built, its gross tonnage, and the size of the crew. As these various fishing effort inputs increase due to the entry and exit behavior of vessels, fleet size declines. According to economic theory, a given level of fishing effort can be maintained with a smaller fleet if the fishing power of the individual vessels increases. Fewer vessels of increased fishing power need to enter the fishery to meet the increased fishing effort requirements caused by improving economic or biological conditions.

One period lags on these independent, explanatory variables also resulted in some significant correlation coefficients with fleet size. Using a one period lag improved the correlation coefficient for crew size, gross tonnage, and vessel length. Declines in these fishing effort variables in previous time periods were highly correlated with fleet size increases in the present time period. The lagged relative cost variable was negatively correlated to both fleet size and vessel entry levels. As costs increased relative to revenues in the previous time period, fleet size and entry levels declined in the present time period. This discrete time element suggests that vessel entry and exit behavior is strongly affected by changes in economic and biological conditions in the past; a new equilibrium fleet size is not obtained instantaneously.

Model

Vessel entry and exit behavior as can be seen in Figure 12 is a strong, dynamic force in determining fleet size overtime. Approximately ten percent of the vessels in the fleet are engaged in this activity in any given year. The size of the fleet grows or declines depending on which force is stronger: net entry or net exit. For example, in Figure 12, fleet size grew from 1975 to 1980 when the level of entry was greater than the level of vessel exits. From 1973 to 1975, net entry was negative and fleet size decline. Since net entry is an on going, dynamic process, underlying economic and biological conditions must be the causal factors determining this behavior.

A simple set of econometric equations was developed to determine if the causal variables that underlie vessel entry and exit behavior could be identified. In these equations, fleet size is determined to be a function of the effort inputs in the fishery (trips, crew size, gross tonnage, and vessel length) and a revenue relative to cost index. Since the costs of maintaining a given fleet size are unknown, the prime rate existing at the time the vessel was constructed was used as a proxy variable. The prime interest rate would be closely related to the interest rate used on the construction loan. Revenue was based on exvessel price and pounds landed per vessel. Lastly, an annual fleet size equilibrium level was assumed to be achieved.

If, in equation (1), all the effort variables were equal to zero and the price, cost, and pounds landed variables were set at their mean values, the fishery could support 15,216 vessels. As the effort inputs increase in value, fleet size would decline to maintain the same total effort level.

$$FS = 3.14(P-\mu)QX/R - 17{,}670.1 - 353.9T - 300.8G - 89.6C - 712.0L \tag{1}$$

where
P = ex-vessel price
μ = resource scarcity rent
QX = pounds landed
R = mean prime interest rate weighted by year of vessel construction
T = trips per vessel
G = gross tonnage
C = crew size
L = vessel length
FS = fleet size

For example, a one unit increase in the size of the crew would result in a decline in fleet size of 89.6 vessels if the total effort level were to remain unchanged. Also, as cost (R) rise relative to revenue (PQX), fleet size will decline by 3.14 vessels for each one unit decrease in the value of this ratio $\{(P-\mu)QX/R\}$. Increases in the price component of this ratio will increase the size of the fleet this resource can support.[7]

A second approach to determining fleet size changes caused by the economic and biological conditions in the fishery is to relax the static equilibrium assumption and assume a dynamic model using lagged variables. The correlation coefficients for a one period lag presented in the previous section indicate that fleet size changes may be influenced by changes in economic and biological conditions in previous time periods. The lagged model of fleet size in equation (2) suggests that increases in trip per vessel or in crew size in a previous time period results in the net entry of vessels into the shrimp fishery.

$$FS = 1.54PQX/R_1 + 2837 + 878.1T_1 - 3328.9G_1 + 124.8C_1 + 288.3L_1 \qquad (2)$$

where
FS = fleet size
T_1 = trips per vessel in the previous time period
G_1 = gross tonnage in the previous time period
C_1 = crew size in the previous time period
L_1 = vessel length in the previous time period
PQX/R_1 = resource value relative to cost in the previous time period

That is, other fishermen perceive these increases in effort variables as an indication that conditions in the fishery have improved. As prices or pounds landed increase relative to costs, fishermen perceive directly that the economic and biological conditions in the fishery are improving. These trends induce them to enter the fishery during the next season and net entry into the fishery increases.

While both of these equations are statistically significant, neither is adequate for predicting changes in the size or structure of the fleet. The models represented by equations (1) and (2) while loosely based on economic theory are too simplistic to be a realistic representation of the fleet. However, both equations do indicate that statistically significant economic relationships exist within the data set assembled from the SLF and the VOUF. The development of a sophisticated, realistic model in

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7 One important implication of the theoretical derivation of this equation was that the coefficient of the relative revenue variable should be equal to one. Since the estimated coefficient is statistically different from one, the assumptions of the model need to be revised to better reflect the actual behavior of fishermen.

conjunction with better cost and returns data, discussed below, should result in a better representation of vessel behavior.

CNR Data

The previous discussion of vessel entry and exit behavior using the SLF and the VOUF data sets did not include shrimp vessel operating cost information. As indicated by the price/cost ratio, using the mean prime rate as a proxy variable for vessel construction costs in Table 2, the costs of operating a vessel have a significant impact on the size of the fishing fleet. The lack of vessel operating cost information would seriously handicap any economic analysis of the Gulf of Mexico shrimp fishery, especially an analysis of vessel entry and exit behavior. Fortunately, vessel operating costs can be estimated using the 1982 survey data collected by the NMFS in 1983. Since the vessel's operating behavior is revealed in its cost and revenue structure, operating costs can be interpolated and extrapolated for other vessels exhibiting the same behavior using economic theory.

Theory

The profit function of the firm in the Southeastern Region shrimp fishery may be represented by:

$$\pi = \sum_{j}^{9}\sum_{i}^{8} P_{ji}\,h_{ji} + \sum_{j=10}^{\infty}\sum_{i}^{N} P_{ji}\,h_{ji} - \sum_{k}^{M} C_k\,x_k \tag{3}$$

$$\text{s.t.} \quad \sum_{j}\sum_{i} h_{ji} = \sum_{j}\sum_{i} q_{ji}X_{ji}E$$

where
π is the profit level of the firm
P is the exvessel price for species (j) of size (i)
h is the harvest level of species (j) of size (i)
j = 1,...,9 species of shrimp
j = 10,...,∞ species of other fish harvested
i = 1,...,8 size classes of shrimp harvested
i = 1,...,N size classes of finfish species harvested
C is the unit cost of the (k) factor inputs
x is the quantities of the (k) factor inputs used in the production process
q is the catchability coefficient for each species (j)
X is the biomass of each species (j), and
$E = f(x_k)$ is the fishing effort level

Each firm or vessel is assumed to maximize profits subject to an output constraint. A Lagrangian can be formed, whose first order conditions can be solved for each factor input used in the production process:

$$x_k = x_k(C_k, h_{ji}) \tag{4}$$

That is, the demand for input x_k of an individual fishing firm that maximizes its profit subject to an output constraint on harvest levels is a function of the input costs and the harvest level of species j of size i. If, over the time period of the analysis, some of the factors of production making up effort are fixed, then the physical quantities of those factor inputs are used in the derived demand equation for x_k instead of their unit cost, e.g.

$$x_k = x_k(C_k, \bar{x}_f, h_{ji}) \tag{5}$$

where
x_f is a vector of fixed factor inputs used in the production process, such as the gross tonnage or vessel length.
x_k is now a vector of the variable factors of production.

Multiplying the derived demand equation for a factor input by its unit cost results in a factor cost equation and it is a simple step to derived a functional form for the cost function:

$$TVC = \sum_{k}^{M} C_k x_k = TVC(C_k, \bar{x}_f, h_{ji}) \tag{6}$$

where
TVC is total variable cost.

A fixed cost function is suggested by the economic theory of the firm. Fixed costs are incurred regardless of the level of production or the unit costs of the variable factors of production. These costs are a function of the fixed factors of production (insurance costs to replace a large vessel are greater than for small vessels), the interest rates on the vessel's construction loan and on the firm's loan for working capital, and the firms depreciation schedule.

$$FC = FC(r_c, r_w, x_f, d) \tag{7}$$

where
r_c is the interest rate on the construction loan for the vessel
r_w is the interest rate on the working capital loan for the firm
x_f is a vector of fixed factor inputs, and
d is the depreciation schedule used by the firm.

Econometrics

An econometric analysis of the 1982 cost and returns survey data was conducted to determine if the implications of the theoretical model were borne out by actual fishermen's behavior. Equations were estimated for the derived demand for fuel and for total variable cost and fixed cost. The functional form of these derived demand and cost equations reflects a Cobb-Douglas production function as an output constraint.

The estimated derived demand for fuel is presented in Table 3.[8] The coefficient of determination adjusted for the degrees of freedom (adj R-sq) indicates that the model explains 77.4% of the variation in fuel demanded by profit maximizing firms that are subject to an output constraint. The coefficient for fuel price is negative, indicating an inverse relationship between quantity demanded and price as theory requires. The anti-log of the intercept term is positive which causes the derivative of quantity with respect to fuel cost to be negative fulfilling the second order requirements for profit maximization, i.e.

$$\delta^2 L / \delta C_k 2 < 0.$$

The level of landings was included in the model and was found to be statistically significant as predicted by the economic theory of a profit maximizing firm subject to an output constraint.

Table 4 presents the results for the estimation of a total variable cost equation. Total variable cost consists of fuel costs, ice costs, engine and gear repair and maintenance cost, cost of supplies and groceries, crew and captain share and bonus, heading and packing, helpers fees, wages, unloading fees, travel expenses, and diver fees. The coefficient of determination adjusted for the degrees of freedom indicates that 93.4 percent of the variation in total variable costs is explained by the model. This seems exceptionally high for cross sectional data, however, the calculated F value (63.303) is significant at the $\alpha = 0.0001$ level and the error degrees of freedom were large.[9] This data was originally collected in 1983 to estimate exactly this type of model and a great deal of effort was put into ensuring that the correct information was collected from a stratified, random sample of vessels in the shrimp fishery. Table 5 presents the results for the fixed cost equation. Fixed costs consist of interest on both vessel construction and working capital loans, cost of the hull, insurance, depreciation, fees for accounting, license, docking, professional, management, state, legal, and vessel documentation,

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8 Variable definitions are provided in Table 6.

9 The degrees of freedom for the model are 35, the error degrees of freedom are 119, and the total degrees of freedom are 154. Total observations in the data set for this regression analysis were 155 (33 observations had missing values).

county property and city taxes, truck, telephone, and office supply expenses, inspection, vehicle expenses, and vessel survey. The coefficient of determination adjusted for the degrees of freedom indicates that 80.4 percent of the total variation in fixed costs of vessel operations are explained by the model. As with the total variable cost equation, the calculated F-statistic is significant at the $\alpha = 0.0001$ level and the error degrees of freedom are 152 out of 184 total degrees of freedom in the model. The independent variables that appear to have the greatest impact on predicting fixed cost are the interest rate on the vessel construction or purchase loan, the hull construction material, and the type od depreciation method used by the owner. Of the fixed vessel characteristics, vessel length had the strongest statistical significance with costs increasing with vessel size. Increasing fixed costs with vessel length reflect the higher insurance costs (more expensive to replace a larger boat than a smaller one, increased liability risk if a crew member is injured because of the larger size crew, docking fees usually are charged per foot of vessel, etc.).

Although additional analyses are required, these results indicate that operation costs for other vessel operating in the fleet can be estimated based on their fixed vessel characteristics, the unit costs of the variable factor inputs, and their reported level of landings. For years other than that for which the survey was conducted (1982), the producer price index (PPI) for various categories (fuel, machinery, etc.) can be used to inflate or deflate the input cost variables. The shrimp landings file can provide information on landings per vessel and the vessel operating units file can provide information on the fixed factors of production such as vessel length as well as some of the variable factors of production such as crew size. Once these models are estimated, the profitability of the shrimp fishing vessels in the fleet for any given year can be estimated and used to determine entry and exit behavior.

Conclusions

Combining information from the VOUF and the SLF created a data set from which the effects of changing economic and biological conditions on fleet size in the Gulf of Mexico shrimp fishery could be modeled. The vessel entry and exit behavior patterns found in the VOUF could be explained using the economic, biological, and effort information contained in the combined data set. Although the vessel entry and exit behavior patterns found in the two data files were inconsistent, the economic and biological data in the SLF on a per vessel basis was consistent with the trends found in the VOUF.

The correlation coefficients demonstrated that strong relationships existed between fleet size and vessel entry levels with various economic indicators of cost, exvessel price, and revenue. Vessel exit behavior was not found to be correlated with these indicators, instead fishing effort variables such as trips per vessel increased as economic and biological conditions declined. As a result, entry occurred when economic conditions improved and fleet size increased. As economic and biological conditions declined, however, vessels attempt to remain in the fishery by increasing their share of landings.

Utilizing the economic theory of the firm, the 1982 cost and returns survey conducted by NMFS can be used to estimate operating costs based on vessel characteristics, unit costs of the variable factor inputs, and the reported level of landings. The derived demand and fixed and variable cost equations were statistically significant and the estimated coefficients complied with economic theory. Using the estimated equations, information from the VOUF on vessel characteristics and the SLF on landings and mobility, and the producer price index to inflate and deflate factor costs over time, reasonable estimates of vessel operating costs can be derived for other years and used in an analysis of entry and exit behavior.

The comparison of the VOUF and the SLF, the correlation between entry and exit behavior as determined by the VOUF with economic variables from the SLF and other sources, and the use of the CNR data set to estimate cost equations for vessels in these fisheries indicates that a viable data set can be generated from the combination of the VOUF, SLF, and CNR data sets on an individual vessel basis. Using the VOUF, vessel entry and exit behavior and vessel characteristics can be determined based on the USCG vessel documentation number. The SLF can provide information on vessel landings, trips, exvessel prices, and pounds landed for those vessels identified in the VOUF by their USCG documentation number. Information from this combined set of data can be used in conjunction with the estimated cost equations from the 1982 CNR survey to estimate vessel operating costs. This combined data set can then be used to determine the causal factors that underlie the observed vessel entry and exit behavior patterns with a high probability of success.

Figure 1

VOUF AND SHRIMP LANDINGS FILE VESSELS

1966–1979

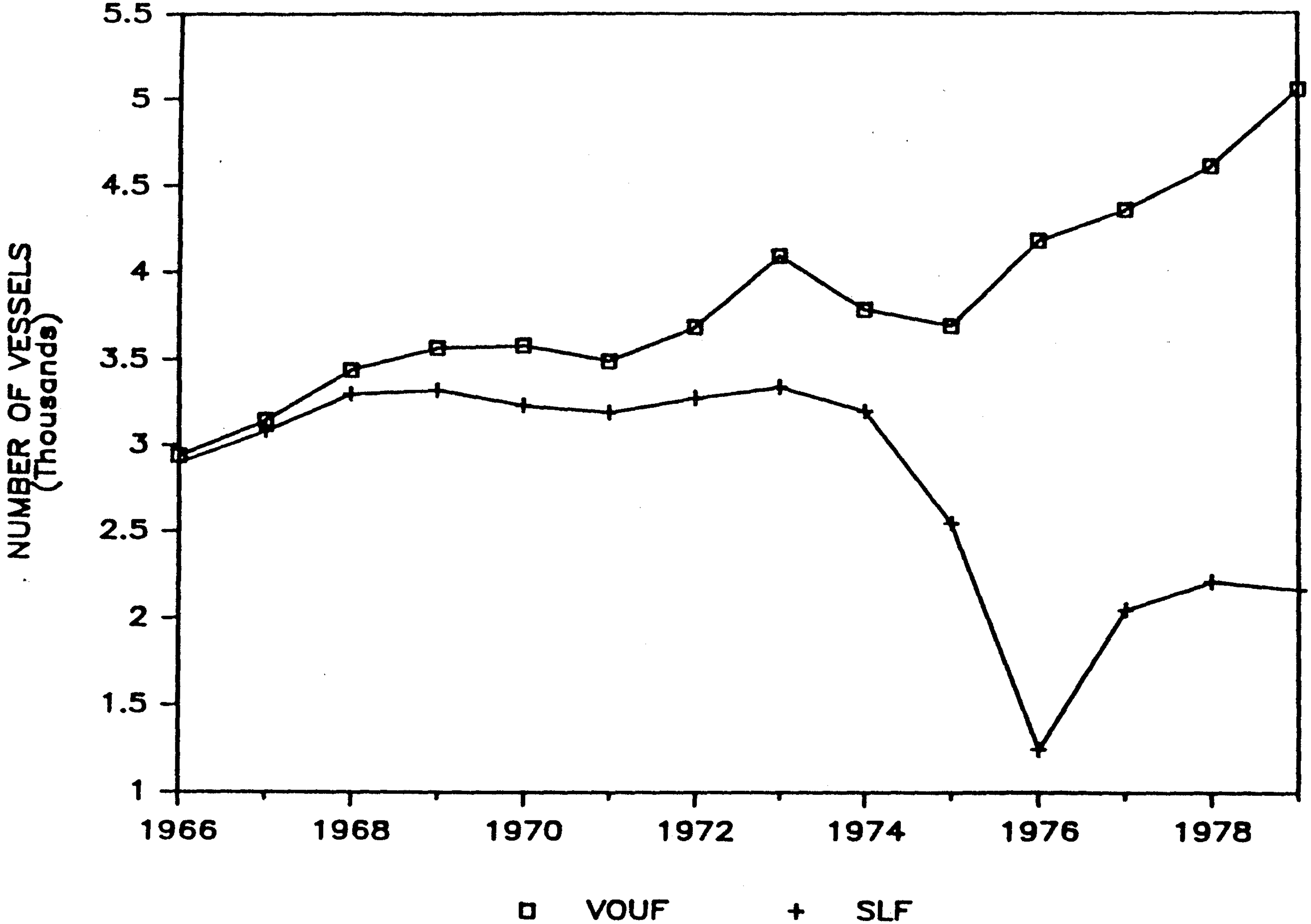


Figure 2

VOUF AND SLF VESSEL ENTRY

1966–1979

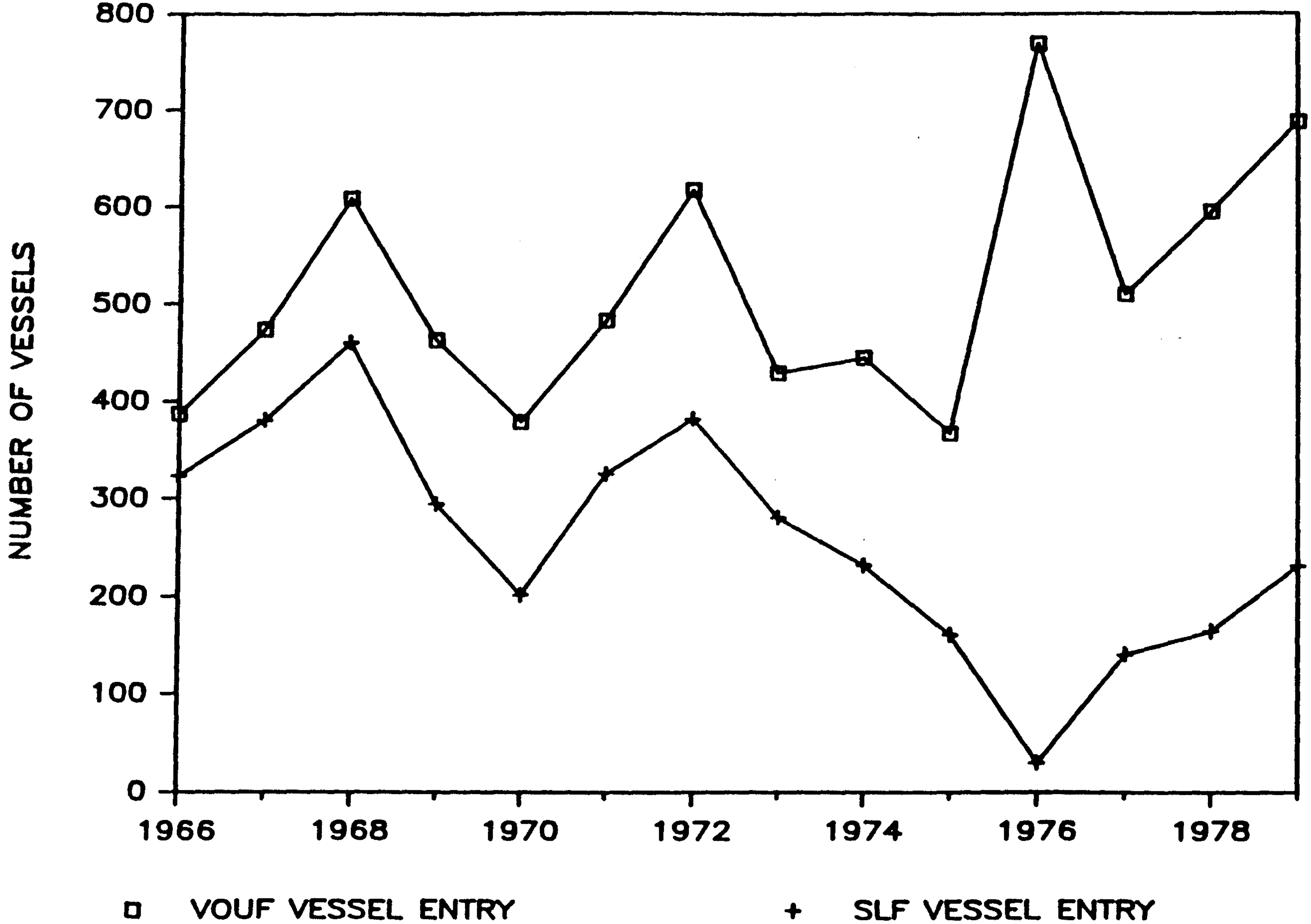


Figure 3

VOUF AND SLF VESSEL EXITS

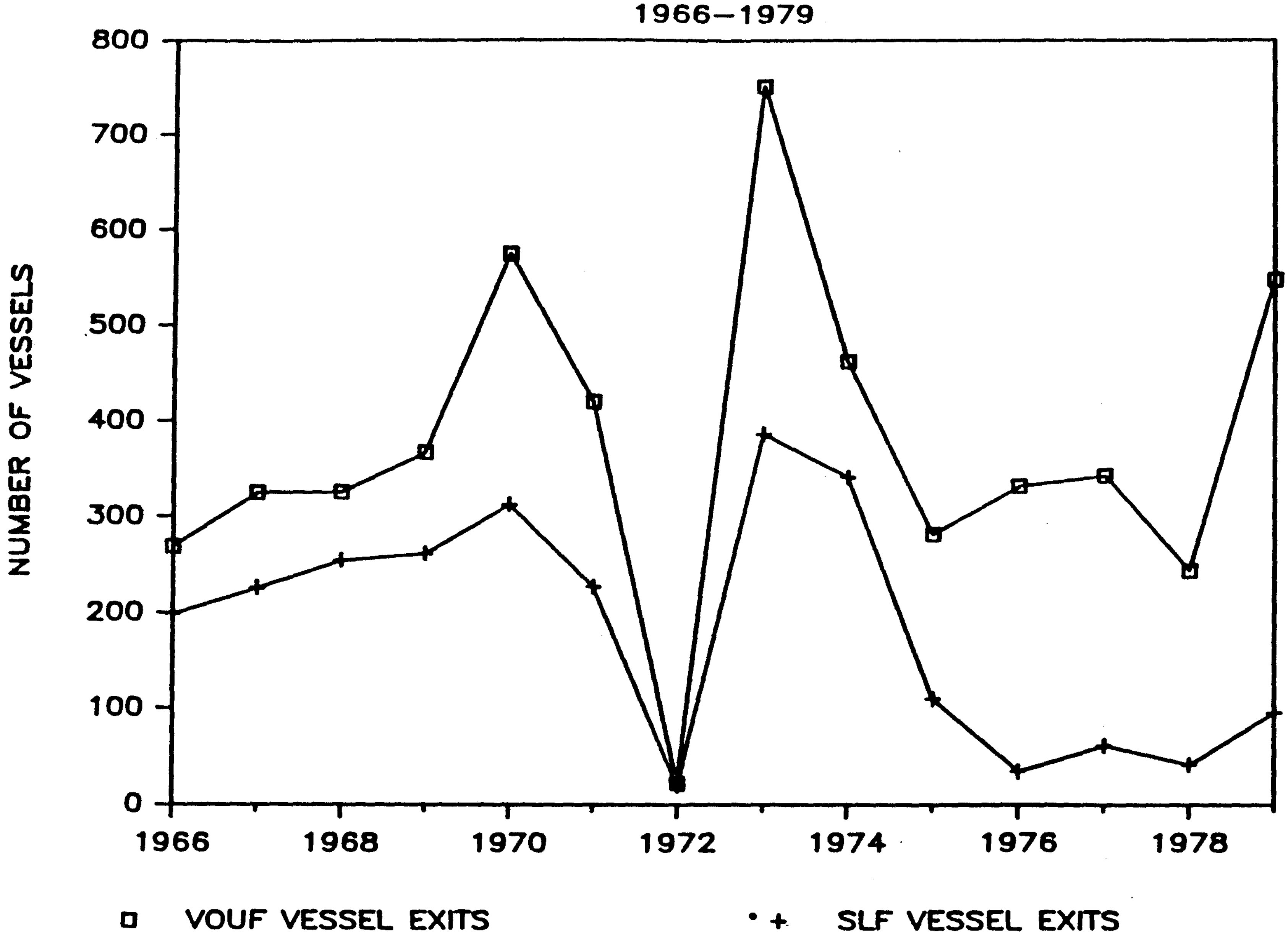
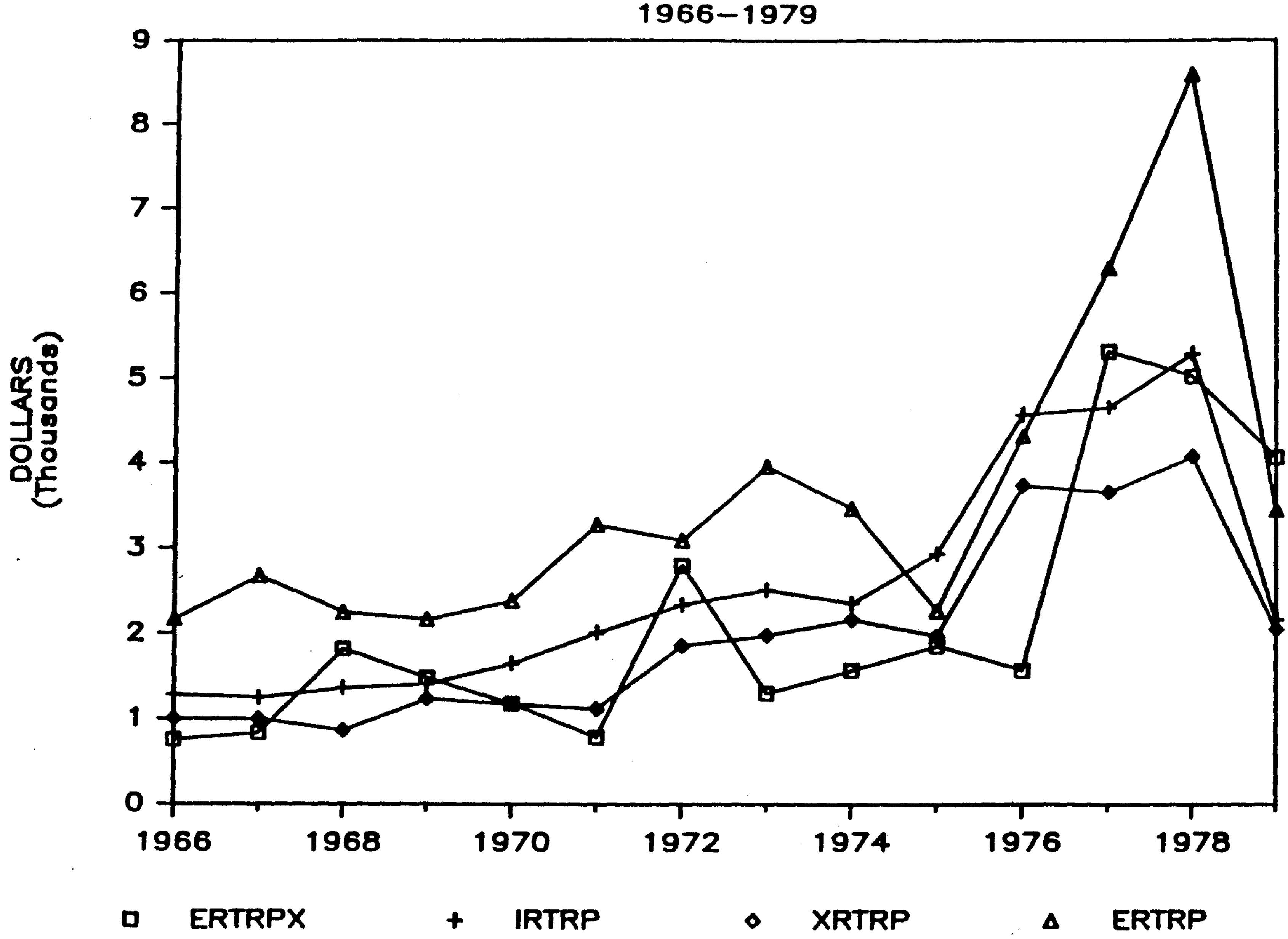


Figure 4

REVENUE PER TRIP BY BEHAVIOR CATEGORY



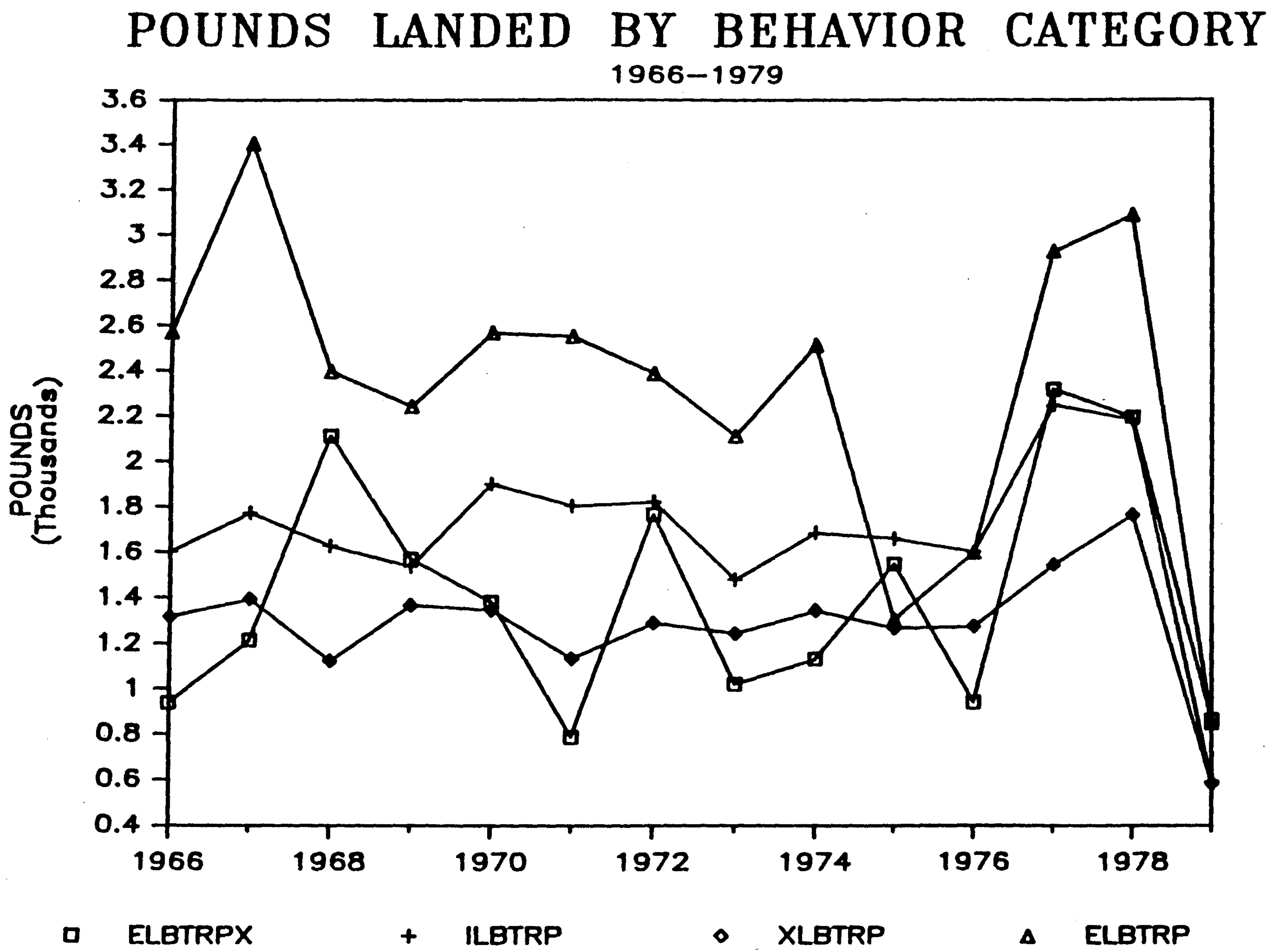
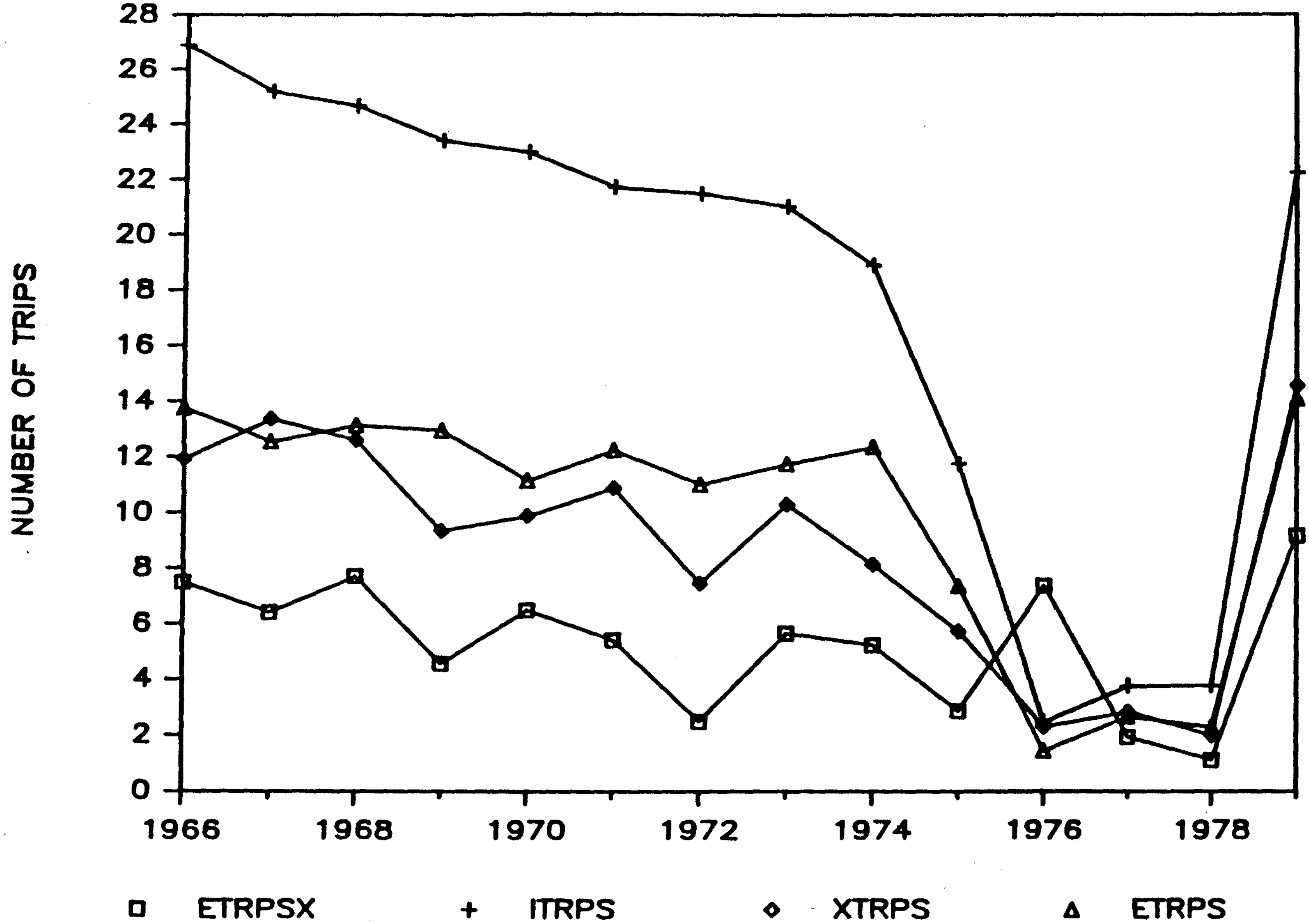

POUNDS LANDED BY BEHAVIOR CATEGORY
1966–1979
POUNDS (Thousands)
3.6
3.4
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
1966
1968
1970
1972
1974
1976
1978
ELBTRPX
ILBTRP
XLBTRP
ELBTRP

Figure 6

VESSEL TRIPS BY BEHAVIOR CATEGORY

1966–1979



VESSEL GROSS TONNAGE + OR − 1 S.E.

1965–1980

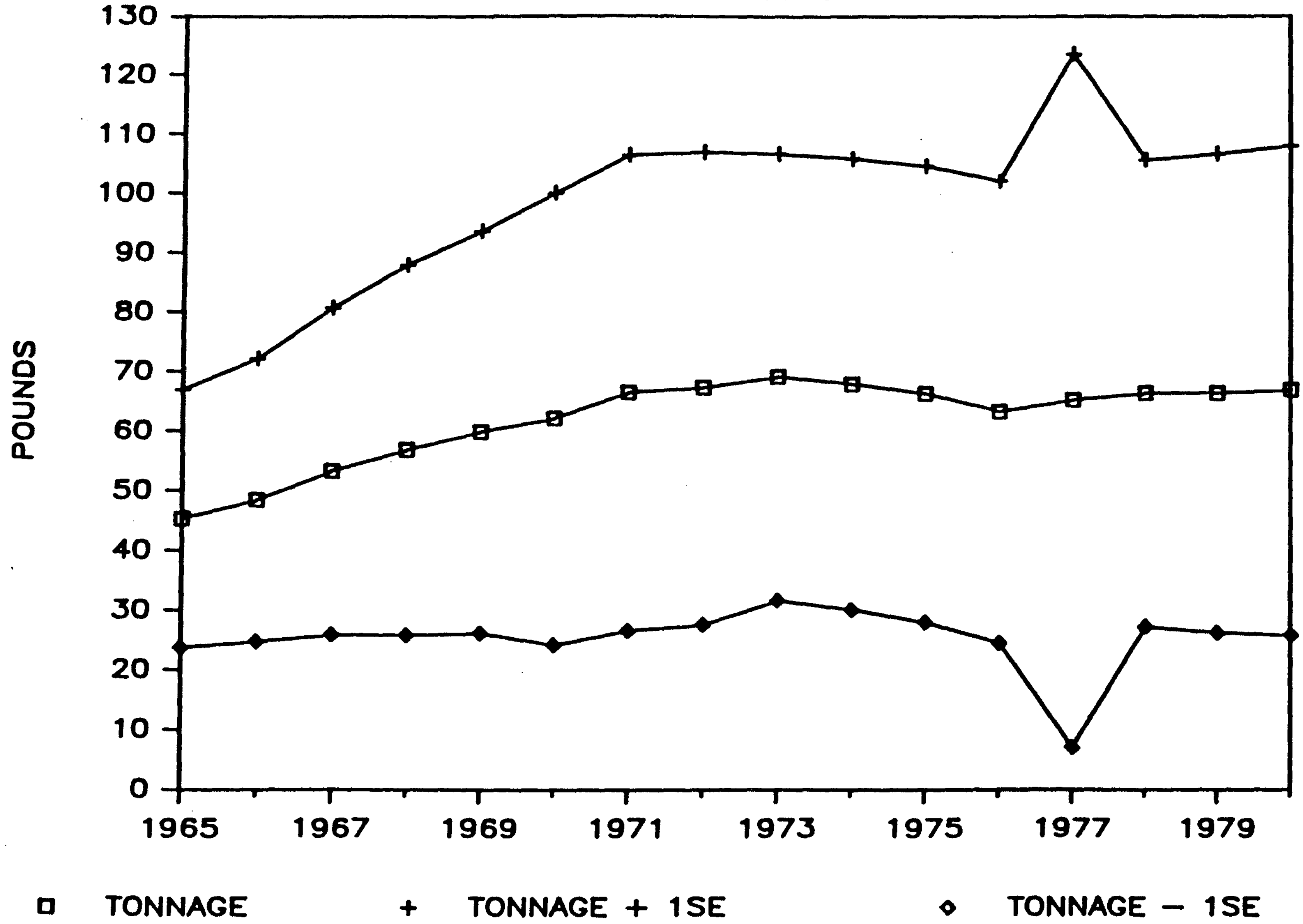


Figure 8

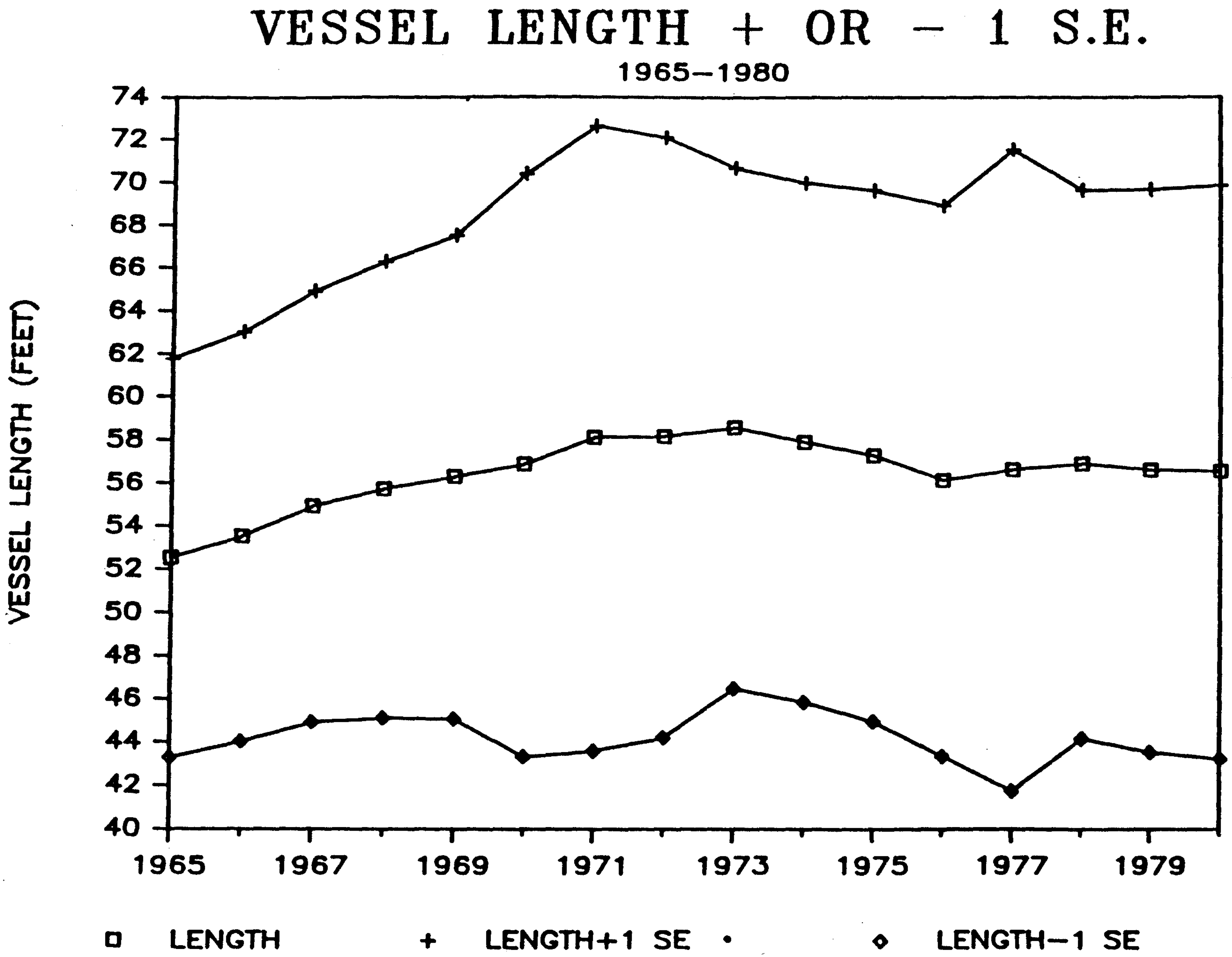

VESSEL LENGTH + OR - 1 S.E.
1965-1980
VESSEL LENGTH (FEET)
74
72
70
68
66
64
62
60
58
56
54
52
50
48
46
44
42
40
1965
1967
1969
1971
1973
1975
1977
1979
LENGTH
LENGTH+1 SE
LENGTH-1 SE

Figure 9

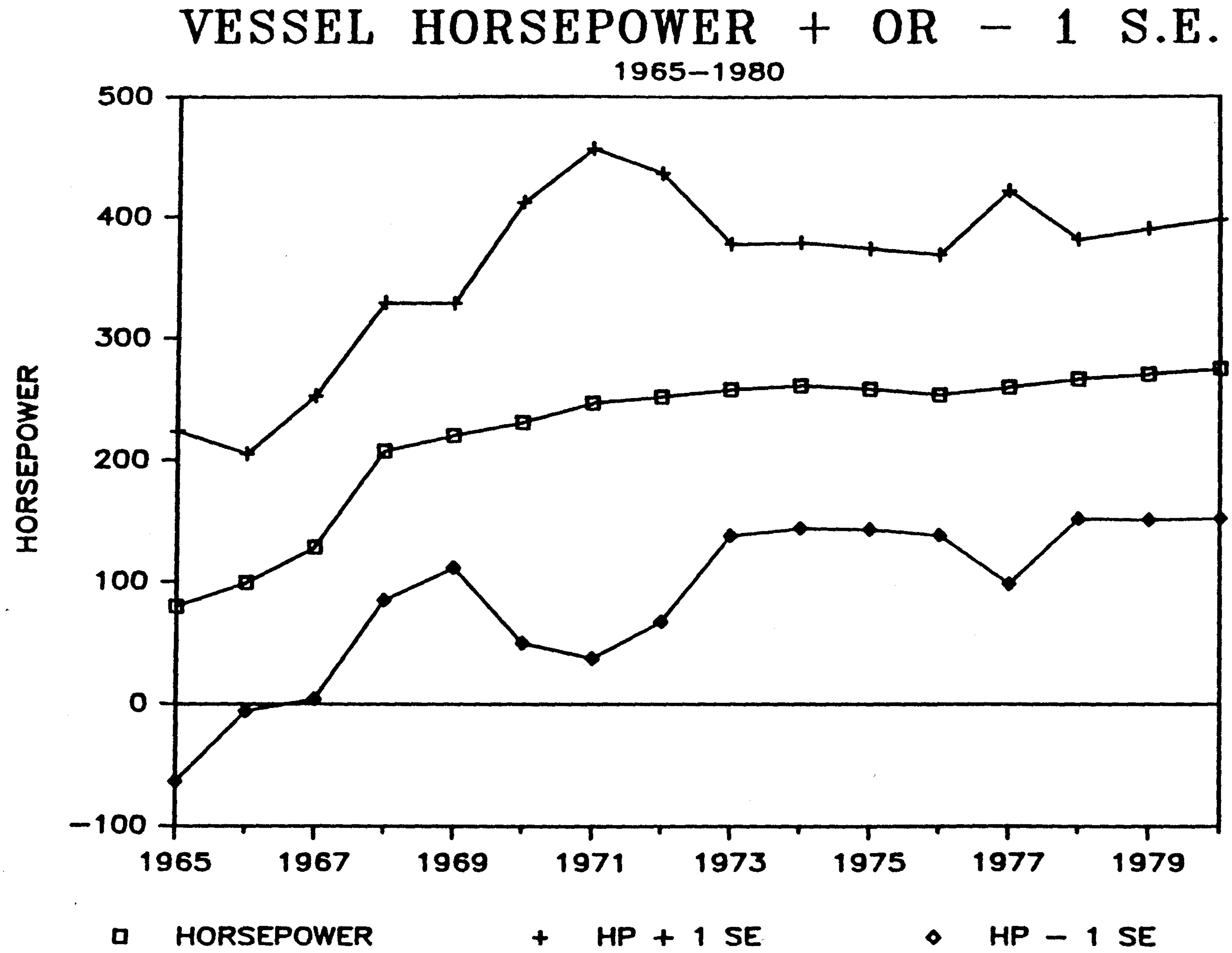

VESSEL HORSEPOWER + OR − 1 S.E.
1965−1980
HORSEPOWER
500
400
300
200
100
0
−100
1965
1967
1969
1971
1973
1975
1977
1979
□ HORSEPOWER
+ HP + 1 SE
◇ HP − 1 SE

Figure 10

VESSEL CREW SIZE + OR − 1 S.E.

1965–1980

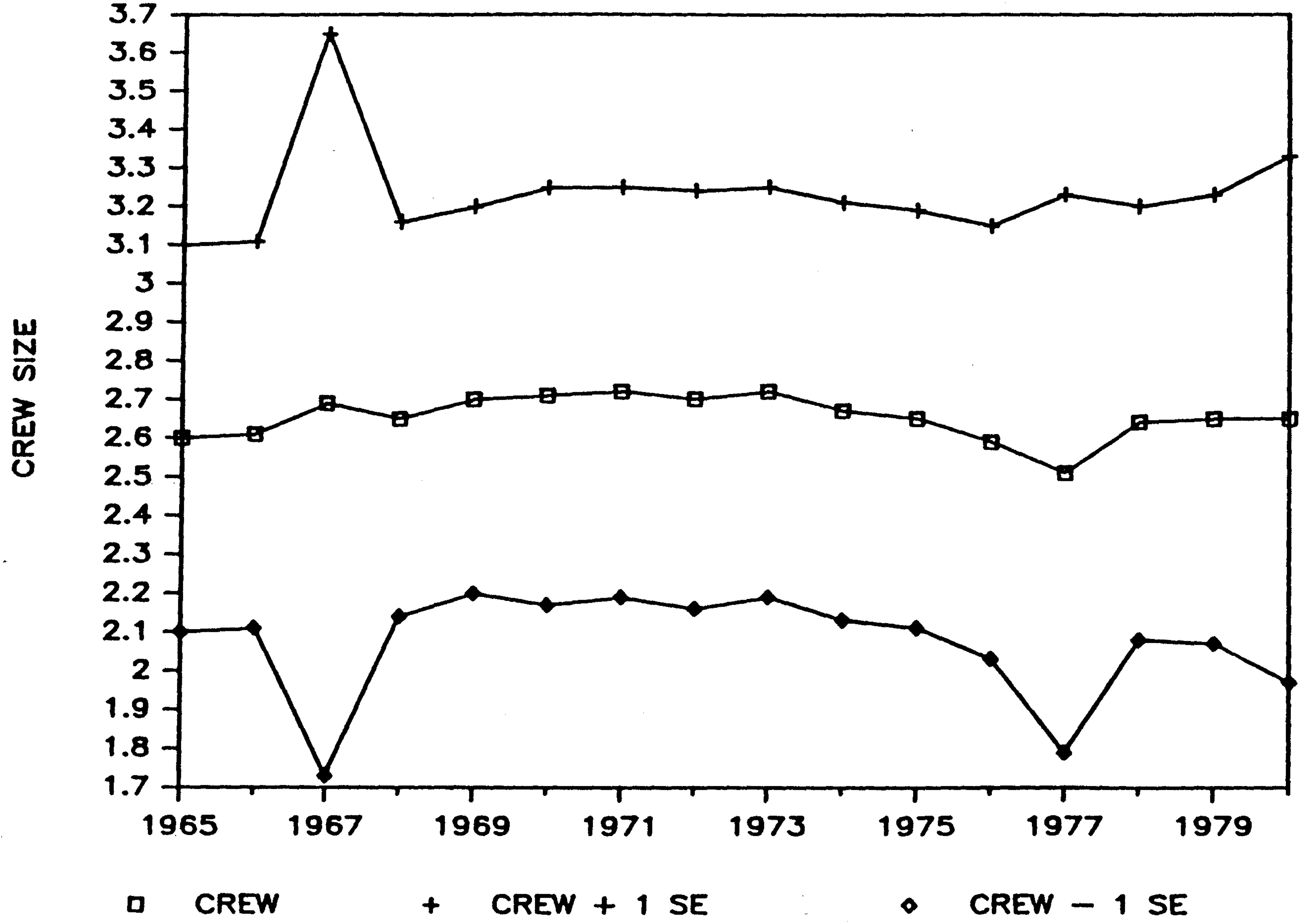
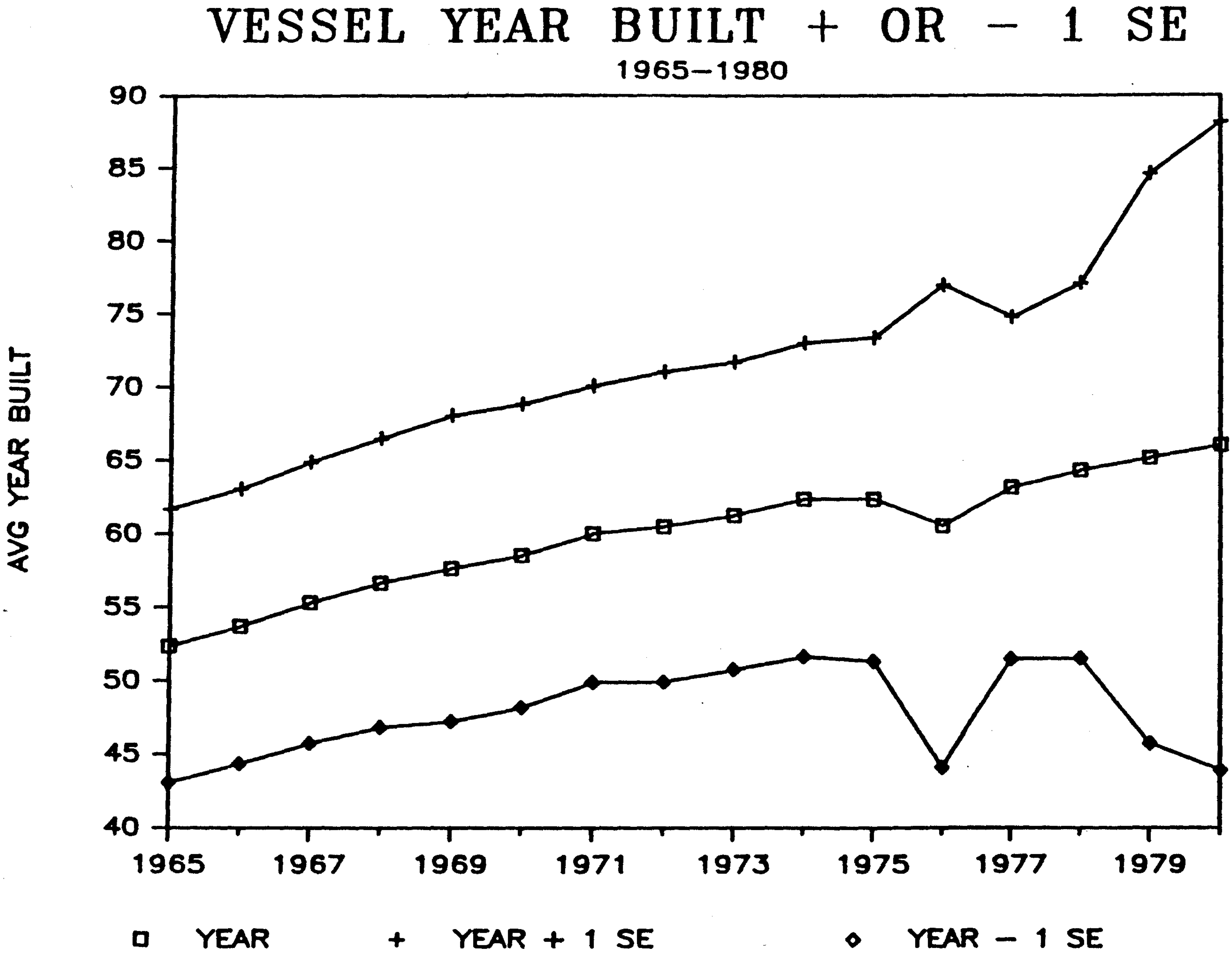


Figure 11



VESSEL YEAR BUILT + OR − 1 SE
1965–1980
AVG YEAR BUILT
90
85
80
75
70
65
60
55
50
45
40
1965
1967
1969
1971
1973
1975
1977
1979
YEAR
YEAR + 1 SE
YEAR − 1 SE

Figure 12

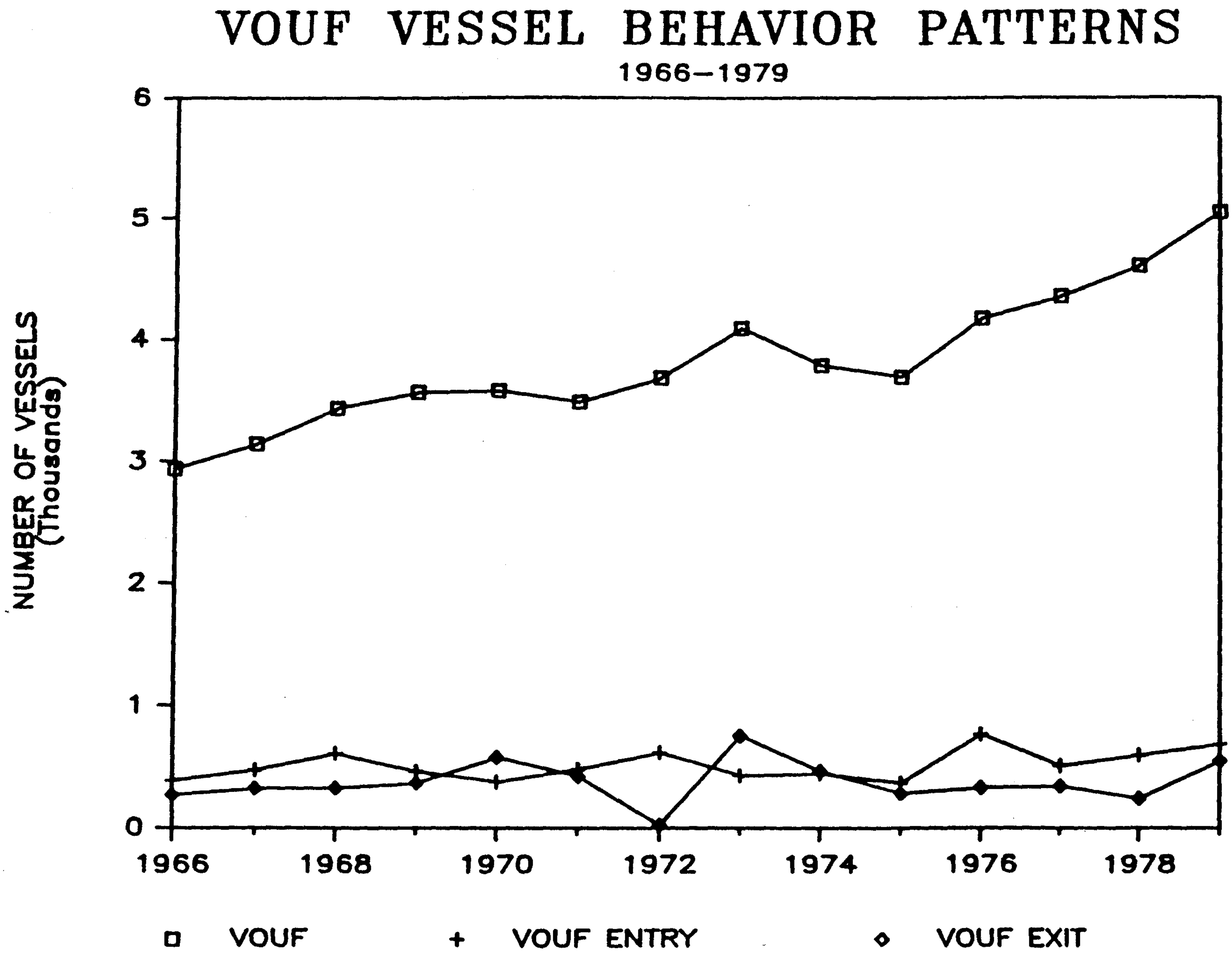

VOUF VESSEL BEHAVIOR PATTERNS
1966–1979
NUMBER OF VESSELS (Thousands)
6
5
4
3
2
1
0
1966
1968
1970
1972
1974
1976
1978
VOUF
VOUF ENTRY
VOUF EXIT

Table 1

YEAR	Vessel In VOUF	VESSEL ENTRY	VESSEL EXIT	MATCHES FOUND IN SLF		MATCHES FOUND ENTRY		MATCHES FOUND EXIT	
	No.	No.	No.	No.	%	No.	%	No.	%
1965									
1966	2941	387	269	2904	98.7	323	83.5	199	74
1967	3146	474	325	3086	98.1	381	80.4	226	69.5
1968	3430	609	326	3298	96.2	461	75.7	255	78.2
1969	3567	463	367	3317	93	295	63.7	262	71.4
1970	3579	379	575	3230	90.3	202	53.3	313	54.4
1971	3487	483	420	3189	91.5	326	67.5	227	54.1
1972	3684	617	22	3272	88.8	382	61.9	20	90
1973	4091	429	751	3336	81.5	281	65.5	386	51.4
1974	3785	445	462	3195	84.4	232	52.1	341	73.8
1975	3690	367	282	2542	68.4	161	43.9	110	39
1976	4177	769	332	1246	29.8	30	3.9	35	10.5
1977	4355	510	343	2049	47.1	141	27.7	62	18.1
1978	4607	595	244	2209	48	165	27.7	42	17.2
1979	5051	688	548	2164	42.8	232	33.7	96	17.5
Avg	3828	515	376	2788	72.8	258	50.1	181	48.1

Table 2

	Fleet Size	Entry	Exit	Trips per Vessel: In the Fishery	Trips per Vessel: Entering	Trips per Vessel: Exiting	Trips per Vessel: Entering and Exiting	Pounds
Fishing Year								
Above Average	0.824	0.671	-0.036	-0.746	-0.695	-0.514	-0.102	
Below Average	-0.625	-0.698	0.301	0.301	0.521	0.433	0.258	
Price per Pound	0.824	0.773	0.069	-0.617				-0.882
Prime Rate	0.928	0.452	0.15	-0.665				-0.855
Price Cost Ratio	0.371	0.751	-0.076	-0.346				-0.556
Trips per Vessel	-0.471	-0.091	-0.098					
Vessel Length	-0.579	-0.278	-0.029					
Year Built	-0.719	-0.757	-0.089					
Gross Tonnage	-0.559	-0.248	0.012					
Crew Size	-0.103	-0.109	0.104					
Lagged Variables								
Crew Size	-0.258	-0.471	0.178					
Gross Tonnage	-0.702	0.335	0.056					
Year Built	-0.497	-0.122	-0.092					
Vessel Length	-0.679	-0.329	-0.01					
Cost Revenue Ratio	-0.428	-0.295	-0.179					

Table 3
Derived Demand for Fuel
Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	-6.627568	2.23069014	-2.971	0.0036
LFP	1	-5.931807	7.55025799	-0.786	0.4336
LIP	1	1.042405	1.27542367	0.817	0.4153
LC	1	-0.121351	0.08566766	-1.417	0.1591
LY	1	0.487567	0.11018636	4.425	0.0001
LTRPDS	1	0.374036	0.08918449	4.194	0.0001
LB	1	1.476046	0.28202561	5.234	0.0001
LAGE	1	-0.042176	0.05816958	-0.725	0.4698
LYON	1	0.025985	0.06716626	0.387	0.6995
LHP1	1	-0.011800	0.15603271	-0.076	0.9398
LHP2	1	0.022288	0.01298129	1.717	0.0885
LY1	1	0.005612	0.01193201	0.470	0.6389
LY2	1	0.003555	0.03202190	0.111	0.9118
LDTRPDS	1	-0.452558	0.10050928	-4.503	0.0001
DTX	1	0.239394	0.11032049	2.170	0.0319
DLA	1	-0.358131	0.14077135	-2.544	0.0122
DMS	1	0.251484	0.15446154	1.628	0.1061
DAL	1	-0.469600	0.16336507	-2.875	0.0048
DFLAST	1	0.015666	0.17330293	0.090	0.9281
DGA	1	0.012300	0.14037481	0.088	0.9303
DSC	1	-0.598320	0.18010419	-3.322	0.0012
DNC	1	0.246526	0.45178727	0.546	0.5863
DSA	1	0.337572	0.20614034	1.638	0.1041
DPI	1	0.499078	0.14703818	3.394	0.0009
LCGPT	1	-0.000915	0.01315711	-0.070	0.9447
LCEPT	1	0.046673	0.01909777	2.444	0.0159
DINT	1	5.099346	1.17811926	4.328	0.0001
LGRC	1	-0.012213	0.00609526	-2.004	0.0473
LPH	1	0.008354	0.03381227	0.247	0.8053
LPC	1	-0.053183	0.03531165	-1.506	0.1346
DHF	1	-0.229581	0.12170224	-1.886	0.0616
DCAPT	1	0.194562	0.08770901	2.218	0.0284

F Value	Prob>F	R-square	Adj R-sq	W:Normal	Prob<W
18.043	0.0001	0.8197	0.7743	0.957657	0.0010

Table 4
Total Variable Cost
Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	2.210794	1.02637959	2.154	0.0333
LFP	1	-5.613239	3.42962008	-1.637	0.1043
LIP	1	-0.744398	0.57997866	-1.283	0.2018
LC	1	0.156886	0.03988641	3.933	0.0001
LY	1	0.569884	0.05054026	11.276	0.0001
LTRPDS	1	0.145193	0.04089261	3.551	0.0006
LB	1	0.529962	0.12914527	4.104	0.0001
LAGE	1	-0.055013	0.02809239	-1.958	0.0525
LYON	1	0.082890	0.03162821	2.621	0.0099
LHP1	1	-0.011033	0.07295918	-0.151	0.8801
LHP2	1	0.003485	0.00609821	0.571	0.5688
LY1	1	0.000698	0.00574628	0.121	0.9035
LY2	1	0.002277	0.01462907	0.156	0.8766
DTX	1	0.315127	0.05052227	6.237	0.0001
DLA	1	-0.070433	0.06272103	-1.123	0.2637
DMS	1	0.186623	0.07234206	2.580	0.0111
DAL	1	-0.166395	0.07404519	-2.247	0.0265
DFLAST	1	-0.168543	0.07902023	-2.133	0.0350
DGA	1	0.097138	0.06398520	1.518	0.1316
DSC	1	-0.208472	0.07523399	-2.771	0.0065
DNC	1	0.429008	0.21090725	2.034	0.0442
DSA	1	0.251808	0.09501135	2.650	0.0091
DINT	1	1.643430	0.53828780	3.053	0.0028
LDTRPDS	1	-0.146374	0.04537908	-3.226	0.0016
DPI	1	0.210012	0.06375161	3.294	0.0013
DNN1	1	-0.191759	0.07556787	-2.538	0.0125
DNN2	1	-0.168373	0.07736532	-2.176	0.0315
DHS	1	-0.593944	0.20781442	-2.858	0.0050
DHW	1	-0.539528	0.19857647	-2.717	0.0076
LCEPT	1	0.050889	0.00883878	5.758	0.0001
LCGPT	1	0.007116	0.00609073	1.168	0.2450
LGRC	1	-0.001002	0.00284186	-0.353	0.7249
LPH	1	0.034601	0.01567294	2.208	0.0292
LPC	1	-0.012688	0.01629513	-0.779	0.4377
DHSW	1	-0.716666	0.29703311	-2.413	0.0174
DHF	1	-0.597804	0.21087267	-2.835	0.0054

F Value	Prob>F	R-square	Adj R-sq	W:Normal	Prob<W
63.303	0.0001	0.9490	0.9340	0.980633	0.4376

Table 5
Fixed Costs
Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	1.963363	1.04789816	1.874	0.0629
LB	1	1.349776	0.26129360	5.166	0.0001
LAGE	1	-0.068685	0.06432820	-1.068	0.2873
LYON	1	-0.087478	0.07014754	-1.247	0.2143
LHP1	1	0.421186	0.17120762	2.460	0.0150
LHP2	1	0.026251	0.01437299	1.826	0.0698
LR	1	0.080539	0.01097931	7.336	0.0001
LRW	1	0.032875	0.01454750	2.260	0.0253
DTX	1	0.293972	0.11696372	2.513	0.0130
DLA	1	0.169981	0.12469886	1.363	0.1749
DMS	1	-0.326049	0.16499935	-1.976	0.0500
DAL	1	0.628144	0.15880081	3.956	0.0001
DFLAST	1	0.305560	0.12998541	2.351	0.0200
DGA	1	0.171798	0.12533637	1.371	0.1725
DSC	1	0.027210	0.12710862	0.214	0.8308
DNC	1	-0.447394	0.32735000	-1.367	0.1737
DINT	1	-0.348658	0.19328797	-1.804	0.0732
DHS	1	0.463028	0.11121573	4.163	0.0001
DHSW	1	0.827223	0.38401394	2.154	0.0328
DHF	1	0.377344	0.13073904	2.886	0.0045
DCAPT	1	-0.250869	0.11205532	-2.239	0.0266
DREC	1	-0.295340	0.11920492	-2.478	0.0143
DDM1	1	0.754330	0.29816727	2.530	0.0124
DDM2	1	0.466477	0.10841010	4.303	0.0001
DDM3	1	0.335439	0.13305593	2.521	0.0127
DDM4	1	1.078035	0.35148669	3.067	0.0026
DDM11	1	0.324883	0.17937881	1.811	0.0721
DDM12	1	0.800188	0.18450549	4.337	0.0001
DDM16	1	1.378468	0.35984395	3.831	0.0002
DDM17	1	0.656526	0.15253311	4.304	0.0001
DDM20	1	1.379735	0.49181689	2.805	0.0057
DDM26	1	1.288304	0.49849837	2.584	0.0107
DDM27	1	0.549371	0.31866756	1.724	0.0867

F Value	Prob>F	R-square	Adj R-sq	W:Normal	Prob<W
24.557	0.0001	0.8379	0.8038	0.957995	0.0002

Table 6
Variable Definitions

Variable	Definition
INTERCEP	Intercept Term
LFP	Fuel Price
LIP	Ice Price
LC	Per Crew Member Income
LY	Annual Level of Harvest
LTRPDS	Annual Days Spent Fishing
LB	Vessel Length in Feet
LAGE	Vessel Age
LYON	Years Vessel has been Owned by the Fisherman
LHP1	Horse Power of the Vessels Power Plant
LHP2	Horse Power of the Vessels Secondary Engine
LY1	Pounds Landed of First Bycatch Species
LY2	Pounds Landed of Second Bycatch Speices
LCGPT	Gear Repair Cost Per Trip
LCEPT	Engine Repair Cost Per Trip
LPH	Packing and Heading Costs
LPC	Processing Costs
LR	Interest Rate on Vessel Construction Loan
LRW	Interest Rate on Working Capital Loan
LGRC	Grocery Cost per Crew Member
	Mobility Dummy Variables
DTX	Landed Shrimp in Texas
DLA	Landed Shrimp in Louisiana
DMS	Landed Shrimp in Mississippi
DAL	Landed Shrimp in Alabama
DFLAST	Landed Shrimp on the East Coast of Florida
DGA	Landed Shrimp on the West Coast of Florida
DSC	Landed Shrimp in South Carolina
DNC	Landed Shrimp in North Carolina
DSA	Vessel Operated on the Atlantic Coast Only
	Trip Dummy Variables
DINT	Dummy Variable for Inshore Trips
LDTRPDS	Multiplicative Dummy Variable for Inshore Annual Days Fished
LDOTRPDS	Multiplicative Dummy Variable for Offshore Annual Days Fished
	Hull Construction Material Dummy Variables
DHS	Steel
DHW	Wood
DHSW	Steel and Wood
DHF	Fiberglass
DCAPT	Data Obtained from Captain Interview
DREC	Data Obtained from Record Examination
	Dummy Variables for Number of Nets Used by Vessel
DNN1	Vessel Used One Net
DNN2	Vessel Used Two Nets